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Stability improvement of thin isotropic cylindrical shells with partially filled soft elastic core subjected to external pressure

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ABSTRACT

Improvement of stability of thin isotropic shell in the presence of soft elastic filler has been investigated. Critical buckling loads for empty and filled cylinder have been studied both experimentally and theoretically using FE analysis. Various percentage of cross sectional filling are examined as a parametric variation. Nonlinear analysis with proper geometric imperfection modeling is carried out to represent correct behavior of soft elastic filler. The experimental results and FE analysis corroborate well to establish this improvement in buckling strength. It is observed that critical buckling load of the cylinder subjected to external pressure improves upto an extent of five times depending upon percentage of filling. It is concluded that improved strength can be utilized for more efficient design of thin tubular shells.

1. Introduction

Thin walled cylindrical shells find wide spread application in rocketry, submarine, submarine pipelines, oil rigs and other pressure vessels. Depending on the application scenario, particularly rocketry in aerospace application, thin cylindrical shells undergo buckling either due to axial

load or external pressure and sometimes both. In certain cases of rocketry, the cylindrical shells are partially filled with soft solid elastic materials (such as solid propellant) with varying percentage of cross sectional area depending upon the need. Contribution of these fillers with respect to empty shell can be significant based on particular application and loading condition. One can optimize the basic structure based on the proportion of contribution from the filler towards improvement of critical load.

Early rocketry research by Seide [1] has reported stability improvement of isotropic cylinder in the presence of soft elastic core both for axial and external pressure. Through theoretical investigation using classical mechanics and also limited experimentation the behavior of thin cylinders have been explained in details. However it is reported by the author that, significant gaps are observed in the experimental data that made it difficult to take advantage of improvement in buckling characteristics of tubes due to the presence of soft elastic core. It is also indicated by the investigator that improvement of buckling strength against external pressure is more than that of against axial load.

Kerr [2] in his theoretical research has considered Pasternak foundation model to handle the presence of elastic core in the cylinder. The author reports a reasonable mathematical model and has derived mathematical relationship to predict critical buckling pressure. However the investigation reports that the analytical treatment is important for explaining certain behavior, but it has limited use in practical problem.

Buckling of thin walled cylindrical shell with foam core under axial compression has been studied theoretically and experimentally by Ye et al. [3]. Author**s** employ Raleigh-Ritz approximation approach for the mathematical analysis. It is reported that critical pressure improves to a maximum of 1.73 times that of empty tube. Inner filling above 10% of radius of cylinder does not give any betterment in axial buckling strength.

Obrecht [4] and others have carried out FE based study on isotropic thin shell partially filled with compliant elastic core under axial load. Two important conclusions have been reported by the authors that axial buckling load carrying capacity improves by 5–7 times of empty shell by filling the shell with compliant core of radial thickness varying from 10% to 90% of cylindrical radius (t/R) and sensitivity of a partially filled thin cylinder to geometric imperfection decreases significantly as that of an empty cylinder.

Analyses of buckling of shells have traditionally solved using classical mechanics or FE method. It is a well-known fact [4] that geometric imperfection, that arises from fabrication of the component, play a significant role in determining buckling strength of

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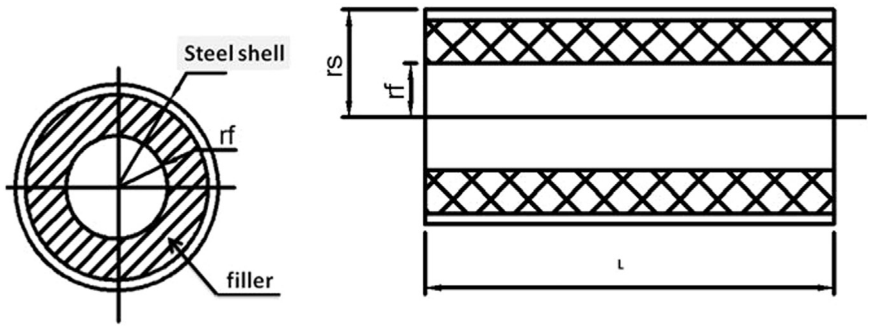

Fig. 1. Geometric definition of test specimen.

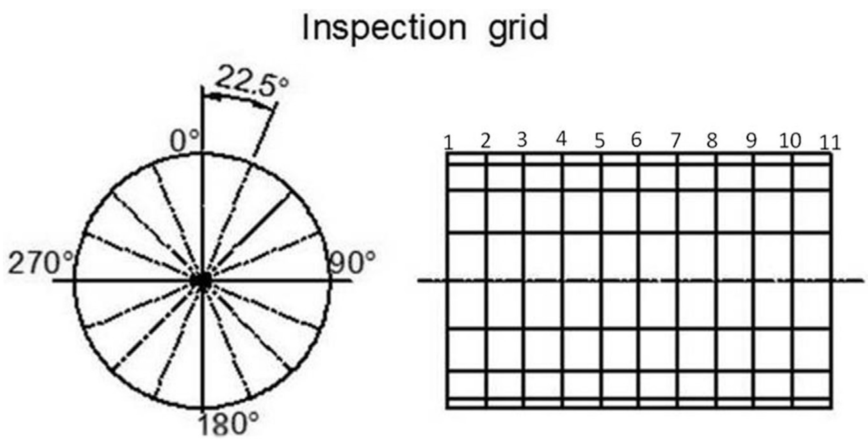

Fig. 2. Dimensional measurement grid.

the component. Waddy [5] has carried out both theoretical and experimental study for predicting buckling strength of empty shells. The author has employed three different approaches to model the geometric imperfection. This includes, Eigen mode shape imperfection, perturbation of lateral load imperfection and single dimple imperfection. It is brought out by the investigator that Eigen mode shape type modeling indicates the lower bound of buckling strength among others. Results are collaborated by the author using experimental data of scaled down and prototype cylindrical shell.

Prabhu [6] and others have used all the following three methods to model geometric imperfection for the analysis. These are, eigen affine mode imperfection pattern, inward half-lobe axi symmetric pattern and local axi symmetric dimple. It is concluded by the authors that, if magnitude of geometric imperfection is less than thickness of the cylinder, Eigen affine mode imperfection gives more realistic buckling load. Hence one can say that Eigen affine/Eigen mode shape method of imperfection modeling is a reasonable model to capture correct buckling strength of a thin cylindrical shell [5,6].

Present work focuses on two parts. First part presents experimental results of thin cylinder made up of steel, filled with soft elastic material of varying cross sectional area. Second part of the work reports the results of nonlinear FE analysis, wherein geometric imperfections are modeled using eigen mode shape. Using both experimental and theoretical results, conclusion is drawn on magnitude of improvement in buckling strength of cylindrical shell.

2. Experiment

Present research focuses on behavior of isotropic thin cylinders with partial filling of soft elastic core towards understanding the buckling behavior. Thin cylindrical shells are realized from high strength steel (Maraging steel, MDN-250) using flow form technique. This technique ensures a good cylindricity and also maximum utilization of raw material in machining. Typically L/D ratio of 3 is chosen for the present experimental exercise. The tubes are internally lined with rocasin rubber of 0.5 mm thickness to ensure good bonding of soft elastic filler. Rocasin rubber is normally used in rocket motor casings as internal insulation. Elastic fillers are casted into these tubes using standard process and the filled tubes are put for curing at a temperature of 45 °C for 4 h to ensure insitu polymerization. Fig 1 schematically shows the basic dimension of filled and unfilled tubes. A total of 18 tubes are used for generating experimental data. Table 2 presents the dimensional detail of each specimen and the corresponding percentage of cross section filled.

Where; r_f is inner radius of filler, r_s is outer radius of steel tube, L is length of tube and Percentage of filling is expressed as the ratio of cross section of area of filler to available cross section area of empty tube i.e. $1-(r_f/r_s)^2$. For the present experiments, $t_s = 0.7$ mm and $R_s = 75$ mm are used.

Geometric imperfections of the tubes are of great significance to know the buckling strength of the structure. Fabricated steel tubes are dimensionally inspected to get a measure of diametrical variation achieved in the fabrication. Fig. 2 presents typical grid followed for measurement. Fig. 3 indicates the variation of diameter as measured. This indicates that with best fabrication effort, imperfection of the order of 10% of thickness can occur in shells. All the 18 tubes have undergone this measurement to get exact nature of imperfection.

The filler material used in the tube is tested for its mechanical properties using ASTM standard D638. The filler material formulation is designed in such a way so as to represent typical HTPB based solid propellant material in its mechanical properties. Formulation used for this inert propellant is presented below in Table 1.